Methodical approach to the provision of spare parts for buses operating in tropical African countries

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Abstract. The article shows the role and features of the operation of vehicles in the tropical region of Africa. The dependence of the reliability of the functioning of transportation company on the climate and local features of operation is noted. A methodological approach to the provision of spare parts for buses is proposed. The issues of management of spare parts reserves for the organization of maintenance and repair of buses are considered.

1 Introduction

Obviously, for the correct operation of rolling stock, a transportation company needs spare parts. Different countries may have different supply of spare parts. If in the countries of Europe, North America and Southeast Asia they are not facing huge difficulties with the supply of spare parts and consumables due to the proximity of their production areas, and well organized logistics. But we observe that in the tropical African countries, the problem of organizing the purchase and storage of spare parts is still relevant.

As you know, a fairly large part of the territory of tropical Africa is located in the region of high mountains. The average annual rainfall is about 1500 mm. The rainy season is from February to May and September to November, and the dry season is from June to August and December to January [1]. A significant part of the territory is foothills and mountains, and, accordingly, transport links are carried out mainly thanks to road transport. In many areas, it is the only possible mean of transport [2, 3].

Almost all buses doing public passenger transportation in African countries are operated in the tropical region, and are manufactured abroad, most of them are made in Japan. The main models are: ISUZU and TOYOTA COASTER. The operating conditions of bus rolling stock in African countries, both climatic and road, are very similar, as well as the system for maintaining the operability of vehicles, in which the current repair of components and assemblies is carried out upon the occurrence of failures, and maintenance essentially includes only the replacement of oil and filters.

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2 Results and discussion

In this regard, the problem of improving the maintenance of the operability of vehicles in the above-mentioned region becomes urgent, including on the basis of the management of reserves of spare parts for car repairs. To obtain statistical information on the reliability of the main components and assemblies, as well as the need for spare parts for buses performing public passenger transportation, a statistical analysis of the reliability indicators of passenger vehicles operated by the state transport company OTRACO, located in the capital of Burundi, the city of Bujumbura, was submitted. The survey included 81 buses manufactured during the time period 2009-2010 (27 ISUZU MV123, 27 ISUZU FRR and 27 TOYOTA COASTER).

In the course of performing work on the analysis of the state of the system for providing the bus companies of Burundi with spare parts for carrying out repairs of rolling stock in order to maintain the working condition of buses. A standard way of collecting information on the reliability of vehicle elements, assemblies, etc., in a digital representation was initially chosen. It provided sufficient accuracy in estimating parameters such as mean time between failures, as well as an estimate of the standard deviation, the coefficient of variation, a reliable selection of the probability distribution laws for the run to failure, etc. However, unfortunately, at moment, in Burundi, since our survey has been focused on 81 buses from OTRACO and not on their entire fleet of buses, then not all the cases collected and included in the analysis tables can be assured of the basic parameter of mileage because of the previous mechanical failure of buses, as well as the total mileage of the bus. Some cases allow monitoring the accumulated mileage by indirect calculations of the mileage on the work performed, on the mandatory number of trips, especially for buses performing intercity transportation and having a small number of completed trips with large travel shoulders. But many cars have deliberately incorrect readings of the accumulated mileage on the speedometers, which, as expected, leads to a significant distortion of the calculation and estimation of reliability parameters, etc.

At the same time, to assess the volume of necessary flows of spare parts for the fleet of buses operated both in a separate OTRACO company, in the regions and in the whole country, there is a need to optimize and streamline the process of supplying components, assemblies, spare parts, other way can be chosen.

For many years, the operation of the existing car park in the country was supported by the purchase and supply of spare parts by both large and, mainly, small private companies of various forms of ownership. A significant problem arising in this case is the fact that it is irrational to purchase very expensive elements - units, components such as an engine, gearbox, rear axle elements, etc., which, moreover, are not often required even in medium and large car companies. since the factor of "freezing funds" is fully working, reducing the return on investment and increasing the risk that a small supplier will not be able to sell the unit on the domestic market of the country for a long time, comparable to the lifetime of the corresponding car model. In this regard, a shortage is created for a certain share of spare parts, which is allowed only by direct purchase of the necessary unit from the manufacturer, or in another, also very far from Burundi, a regional warehouse of spare parts for the corresponding brand, which leads to fundamentally high costs both for private delivery and loss of time leading to a bus downtime waiting for repairs and not performing transport work.

For a private company, the task of organizing warehouse storage for the entire range of spare parts and assemblies with sufficient redundancy, ensuring the elimination of downtime while waiting for spare parts for any, even very rarely required, and expensive elements is difficult and irrational. However, if we proceed from the goal of solving this problem at the state level, the creation of a local regional warehouse of spare parts and assemblies for TOYOTA cars, possibly not only to meet the needs of Burundi, but also for the countries of the East African Union. This synergy of actions will provide resources for reducing the costs of maintenance of the bus rolling stock, both by reducing the costs of emergency orders for the transportation of units, and by reducing the cost of "spare, reserve" buses, which are forcedly purchased in the existing system of bus companies in order to perform the work that is not being done by existent buses due to the lack of (critical) spare parts.

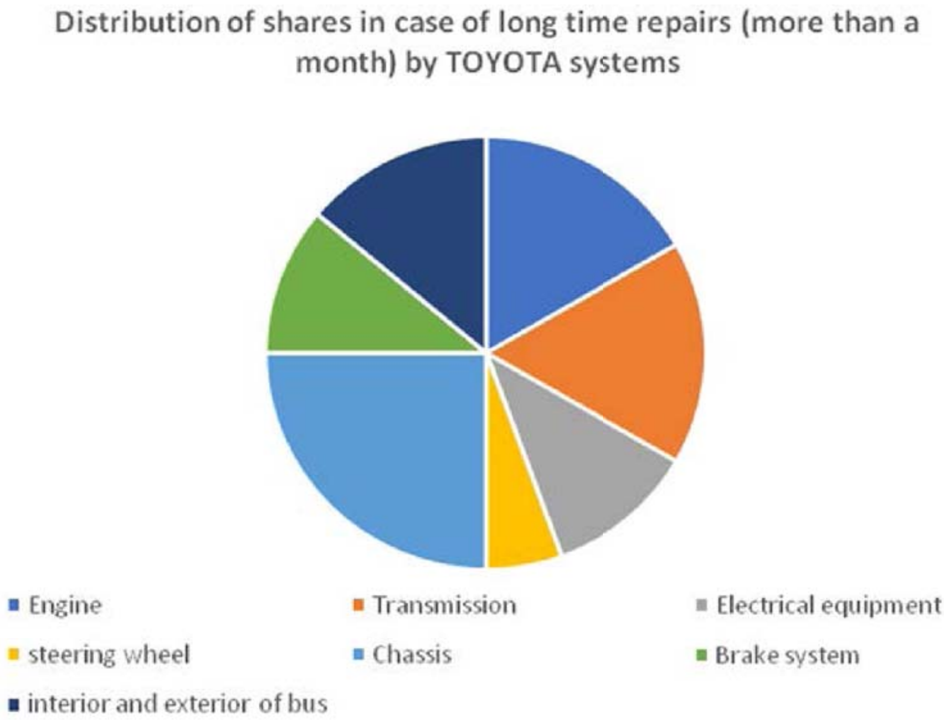

Fig. 1. Distribution of shares of long bus repairs over one month by TOYOTA COASTER systems

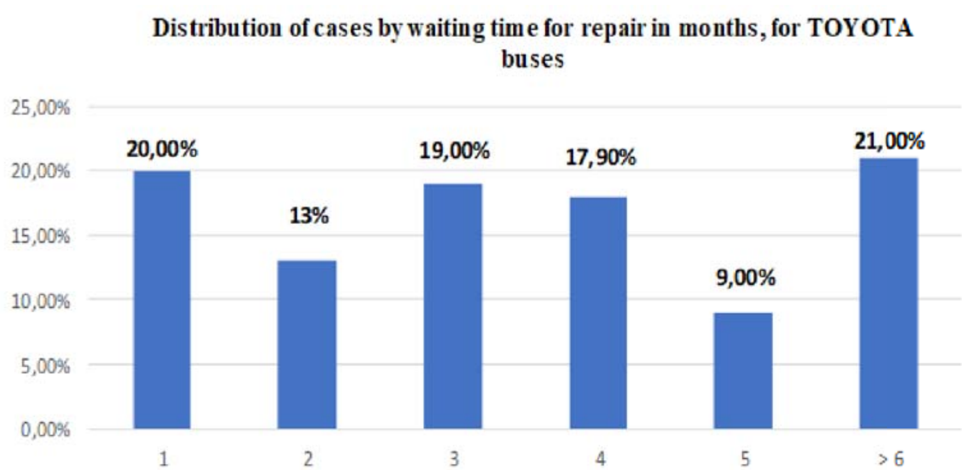

Fig. 2. Distribution of cases by waiting time (in months) for repairing, TOYOTA COASTER

To assess how true, the statements about the loss of time are while waiting for repairs by buses, we submitted a system analysis. Figures 1 and 2 show histograms for TOYOTA COASTER buses, where the downtime considered in this analysis certainly does not fit into the time limit for a bus repair, carried out with all the necessary spare parts. Preliminary analysis shows that only by eliminating long downtime in repairs, the cost of purchasing new buses can be reduced by several percent.

In addition, the already existing practice, which is leading to the occurrence of long downtime pending repair, leads (due to the shortage of spare parts, assemblies) to the emergence of additional financial losses resulting from the operation of the bus with elements that have reached the maximum permissible state, but are not received for repair during lack of necessary spare parts and continuing to work on the line until leaving the line, which entails increased fuel consumption, increased probability of linear failures, derailments, road accidents, increased environmental load, etc.

Thus, having determined, according to the results of the system analysis, the reasons that cause long and ultra-long downtime of buses for repair and the range of spare parts, components, assemblies, as well as knowing, in accordance with the reporting data, the flows of spare parts and new cars purchased for the needs of the republic Burundi, it is possible to determine in value and absolute terms the necessary increase in purchases and centralized supplies of spare parts to cover the existing deficit, provided that a regional warehouse of spare parts has to be created with the definition of rational terms (frequency) of replenishment and permissible irreducible levels of stock of parts.

Considering that the financial components included in the target function required to evaluate various solutions can be proposed to optimize resource support for the technical operation of vehicles. Then, the target function should include those components that respond to control certain actions: the structure of the vehicle fleet, the technical condition of buses ... In this case, the target function can be expressed in the following form:

$$C_{\Sigma} = C_t + C_h + C_{s/p} + C_a + C_{or} + C_{ol}, \quad (1)$$

where C_t – the cost of fuel consumed to perform the main task assigned to the company - the carriage of passengers (in this case) in the necessary amount determined by the leadership (city, state, etc.),

C_h – cost of tires consumed on the same mileage,

$C_{s/p}$ – costs of spare parts, - purchase, delivery, storage, etc.,

C_a – the cost of purchasing buses in the necessary amount to perform the required work within the proposed solution for the management of spare parts stocks,

C_{or} – costs of carrying out and organizing bus repairs.

C_{ol} – costs associated with eliminating bus failures on the line.

In this case, all financial components are taken (for correct normalization) in a specific form, i.e. costs reduced to the unit of mileage of one vehicle, and in each optionally considered for the organization of inventory management, it will be logical to take not the absolute value of one or another component, but the difference with the base value.

To assess the effectiveness, three main options for providing the automotive industry with spare parts are considered.:

1. Each company conducts its own storage facilities independently as it has developed at the present time (basic version);
2. Each company maintains its own warehouse management independently, ensuring an irreducible level of spare parts in its warehouse so that downtime pending repairs in the absence of spare parts does not exceed the permissible limits set based on the average repair time;
3. A centralized base for the accumulation and storage of automotive spare parts is organized, created for the purpose of proper supply of spare parts for transportation companies within the permissible time limits.

Consider the structure of the main components of the objective function – $C_{s/p}$ and C_a.

As shown by the analysis of such a factor as excessive downtime due to the lack of spare parts, which is formed due to the existing delivery system of large, expensive elements, such as an engine, gearbox, rear axle and some others, with an excessive availability of appropriate spare parts in an acceptable proximity to a transportation company, or in the warehouse of the company itself, the proportion of bus downtime for repair during the entire service life will decrease, and therefore the need for the payroll will decrease. Taking this fact into account gives an expression for the specific (per car per year of operation) value C_a:

$$C_a = Z_a \cdot k_{dr} / Y_a, \tag{2}$$

where Z_a – cost of one car,
k_{dr} – redundancy ratio,

$$k_{dr} = t_p \cdot N_a, \tag{3}$$

N_a – the number of cases of long-term repairs per car per year,
t_p – average duration of one forced downtime waiting for spare parts, in years.
In turn, N_a was determined from the information available for the OTRACO company on the group of monitored buses as:

$$N_a = N_\Sigma / (A_i \cdot Y_a), \tag{4}$$

Y_a – observation period for a group of cars,
A_i – the number of cars in the controlled group,
N_Σ – the number of recorded cases of long waiting times for repair.

From the collected statistical data, covering the history of operation of 81 buses of 3 models over nine years, for TOYOTA buses, N_a and t_p indicators turned out to be 0.31 and 0.323, respectively, only for ultra-long downtime (more than a month), which gives at least 10% excess of rolling stock required to perform the work on the transportation of passengers, due only to the non-operational delivery of spare parts. For the other two considered models, this indicator is slightly lower. The costs associated with the purchase, delivery and storage of the requested volume of the required range of spare parts, with the organization and maintenance of warehouse management include several components. The first is the cost of the spare parts themselves. With various schemes for providing and reserving spare parts, the need for the total volume cannot fundamentally change when considering the operation of buses that perform almost fixed (within a certain period of time) work, determined by the needs for transporting passengers in the served region and set at the municipal level. It should be taken into account that when drivers (as well as mechanics, engineering personnel of the company) understand the current situation, in which, when forming an application for repair, it may turn out that the bus will get into a long waiting mode for repairs, there is a high probability that up to a certain level of exceeding the permissible values parameters that determine the technical condition of the vehicle, it will not be taken out of service on the line. This will not only increase the unit costs of fuel, oil consumption, tires, but also increase the likelihood of a line failure with the need to force the bus to be parked for repair from the point of failure, as well as the likelihood of an accident with the need to eliminate the consequences, which is taken into account in the components of the objective function C_t, C_h, C_{or}, C_{ol}, but it will also increase the parameter of the failure rate for these buses that continue to operate in this state. Removing or reducing the share of buses that have been stored for a long period of time will drop the number of buses in circulation that do not meet current technical standards.

However, in order to achieve this goal, funds must be invested either in redundant storage of spare parts in-house, or in buffer storage of spare parts at a centralized regional base. In general terms, expressions for taking these components into account are formed from the following considerations. For each type of spare parts leading to long-term repairs, the level of S_i stock is determined, which must be stored in the warehouse, so that when several orders for this spare parts are received, arising during the time T_i (the time of delivery of these spare parts to the warehouse). There would be a situation of long waiting for a part in the ordering system. So, when the formation of an order occurs after one of these *i* parts left the warehouse to perform the corresponding repair of the bus, i.e. when one node was put on the bus, and an order for delivery is immediately formed, although nodes of this type are still in stock (to maintain a certain irreducible level), and so that a new ordered node arrives with an acceptable probability earlier than the ones still in stock will be consumed. Since we are talking about very rarely required components and parts, the value of the minimum stock level for typical road transport companies in Burundi will lie in the range 1-2.

The cost of storing all these components and assemblies in a warehouse is calculated from the total cost of spare parts required for storage, taking into account the stock described above, with a proportionality factor for their storage (we proceed from the fact that with the current method, spare parts are not specially stored and installed on bus after delivery) - per unit of time, and reduced to one bus. Also, from the value of the irreducible level of stock, losses from dead capital are determined as the product of the cost of these spare parts by the discount coefficient, or bank loan, over the life of the bus model. It is also required to take into account the likelihood that these nodes may not be required at all, which is made by taking into account the cost of all spare nodes, divided by the conditional average life of a bus model, or a group of models using this node.

These calculations are quite the same type both for a separate company and for a combined storage base, with the difference that with very rare consumption in transportation companies when the storage level decreases below a predetermined limit, the process of ordering a unit / unit is immediately started, while on a common warehouse base, the backlash (min.- max. number of storage units) is much larger, i.e., it is not equal to 1, and the order can be made periodically with some optimal period for each node (periods are combined into some pools, by probability, or on the economy), and the corresponding losses are specific to the total number of covered buses. In addition, the cost of purchasing and delivering components and assemblies to a centralized base for each spare part will be lower due to the wholesale nature of purchases.

Thus, the additional costs for the second strategy associated with storing the entire required volume of spare parts in the warehouse of the company itself include:

$$C_{sp} = (\sum_{i=1}^{Np} S_i * Z_i * (k_{s_i} + ((1+k_d)^{Y_m} - 1) \cdot Y_m^{-1} + Y_m^{-1})) / A_c$$

where N_p – the quantity of limiting units, units leading to long downtime in repair for the reasons described above,

S_i – storage level of the i type of spare parts, assembly, unit,

Z_i – cost of one unit of type i spare parts,

k_{si} – proportionality factor of the cost of annual storage of one unit of spare parts of the i type,

k_d – coefficient of loss accumulation (discount),

Y_m – average operating time of the considered bus model,

A_c – list number of buses in the company.

Over the entire period of observations, replacements of the rear axle gearboxes, gearboxes, rear axle, pneumatic hydraulic clutch booster, etc. were noted. The electrical equipment system has also been replaced by starters, generators, etc. In parallel, the analysis of reliability indicators for specific elements of the car was carried out in cases where the reliability of the collected data was not in doubt.

3 Conclusion

The reasons for failures considered in the study and the use of appropriate spare parts for repairing buses made it possible to establish that most of the malfunctions reflect imperfections in the design, disruption of technological processes, the inability of the rolling stock to operating conditions and the imperfection of the currently existing system for maintaining the operability of buses in Burundi, in in particular in the management of reserves of spare parts, components and assemblies. The collected statistical data can be used to determine the likelihood of the need for parts of components and assemblies during certain periods of operation of vehicles performing passenger transportation, which will determine the necessary and sufficient number and range of spare parts not only for buses operated in Burundi, but also in general. for buses in countries of tropical Africa. Based on the collected, analyzed and processed statistical data on failures of the main components, systems and assemblies of buses, a methodology will be formed for determining the minimum necessary and sufficient reserve of spare parts, which will reduce the cost of operating buses rolling stock performing passenger transportation in Burundi and in tropical African countries.

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References

1. M. Nibigira, O. Ntamatungiro, D. Nzeyimana *Burundi vehicle park, Burundi statistical yearbook*, Bujumbura, ISTEEBU vol **3**, 152-157 (2011)
2. N. Ndayishimiye, M. Nibigira, F. Iranyibutse *Burundi vehicle park, Burundi statistical yearbook*, Bujumbura, ISTEEBU vol. **10**. 85-89. (2017)
3. E.C. Kuznezov, V.P. Voronov, A.P. Boldin, V.P. Lukin *Tekhnicheskaya ekspluataciya avtomobilei*, Moscow, Transport 413. (1991)
4. O. Ntamatungiro, R. Muhorakeye *Burundi Bus Service and management guide, Burundi statistical yearbook*, Bujumbura, ISTEEBU V**4** 302 (2012)
5. E.C. Kuznezov, M.A. Nizov *Metodika opredelenia pokazatelii nadiyojnosti avtomobilei*, Moscow, Transport 200 (2002)
6. E.A. Veritelnik Improvement of methods for determining the need for spare parts at the companies of freight road transport, Doctor's thesis, Orel 269 (2019)
7. T.D. Toshev, A.N. Rementsov *Problemy tekhnicheskoj ekspluatacii i avtoservisa podvizhnogo sostava avtomobil'nogo transporta v, Sbornik nauchnyh trudov*, Moscow 218-224. (2017)
8. Gu.Ji *Proactive and Effient Spare Parts Inventory Management Policies Considering Reliability Issues*, Ontario, University of Windsor 265 (2013)
9. N. Marcien, A.N. Rementsov *Problemy tekhnicheskoj ekspluatacii i avtoservisa podvizhnogo sostava avtomobil'nogo transporta v, Sbornik nauchnyh trudov*, Moscow, Tekhpoligrafcentr 152-154 (2018)
10. M. Ngendakumana, A.N. Rementsov *On the issue of managing the technical conditions of rolling stock for passenger traffic in Burundi,* Vistnic MADIMoscow **2(61)** 4-6 (2020)